INTEGRATION OF CORRECTIVE LENSES FOR THE NBC RESPIRATOR AND BALLISTIC PROTECTIVE EYEWEAR

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AIM

The Canadian Forces (CF) are currently pursuing two separate eyewear projects. The first seeks to replace the in-service corrective vision NBC respirator spectacles. The second aims to provide ballistic, solar and laser protection for the soldier's eyes. This paper will present the CF approach to selecting the options available for these two projects and the recommendation to integrate the two requirements for corrective lenses. The results of Human Factors focus groups and field trials will be discussed as well as the technical and optical specifications developed to date.

BACKGROUND

The CF Land Force currently employs two in-service ballistic protection devices; Sand/Wind/Dust Goggles with ballistic insert and Glendale Safety Spectacles. Both devices provide some degree of ballistic eye protection (V_{50} ~ 150 m/s) but are not intended to provide protection for higher energy fragments or to provide facial protection. In addition, the current inservice NBC C4 respirator provides some ballistic protection owing to its polycarbonate eyepieces. While these items provide some degree of protection from ocular threats, it is a temporary fix for limited numbers of troops in specific operations. There are currently two related initiatives underway to improve eye and facial protection provided to soldiers: the Clothe-The-Soldier (CTS) ballistic eyewear project and the Soldier's Helmet Visor Attachment Sub-system project.

The CTS project is a near term soldier modernization program that will purchase, personal protective clothing and equipment items utilizing suitable Commercial Off The Shelf (COTS) items, Near Developmental items (NDI) and designed technologies to meet the specific requirements of today's CF soldiers. The CTS project is developing an integrated two-tiered system of protection to protect the eyes from low energy fragments, particles, laser, solar and UV radiation (ballistic eyewear) and to protect the eyes and face from high energy fragments (ballistic visor) (Clothe The Soldier, 1996). Figure 1 shows a conceptual model recently evaluated. As part of a separate initiative, a prototype Visor Attachment Sub-system (VASS) is being developed and evaluated by the project team for the CF's new Soldier's Helmet (CG 634).

ABSTRACT

The Canadian Forces are pursuing two separate eyewear projects; replacing the in-service corrective vision respirator spectacles and providing protection from ballistic fragments and the sun for the soldier's eyes. The current respirator glasses were developed over twenty years ago while recent developments in materials technology have made new options available. The ballistic protection is a new requirement based upon the escalating rate of eye injuries on the modern battlefield. This paper will examine the options available for integrating these two projects. The results of Human Factors focus groups and field trials will be discussed as well as the technical and optical specifications developed to date.

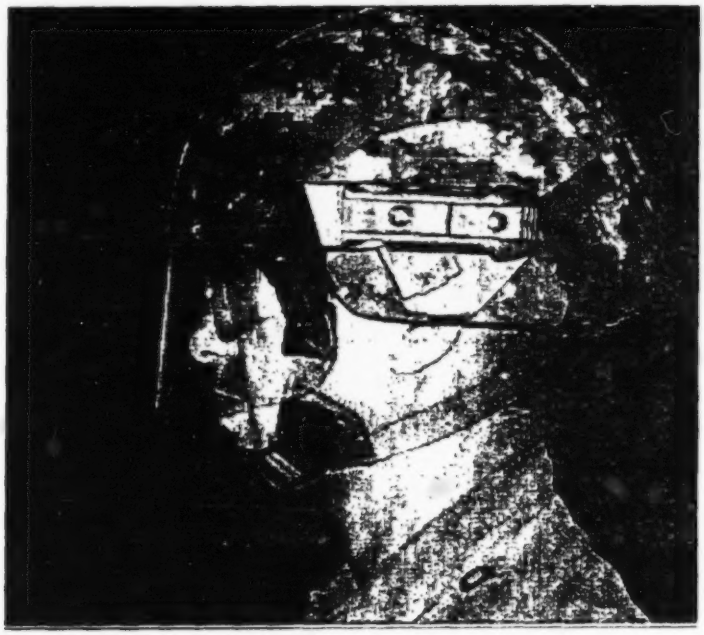

Figure. 1 Conceptual model of tiered oculofacial protection

This tiered approach will ensure that soldiers, based on the threat, can adopt the appropriate level of protection.

Ballistic Eyewear

The threat to the soldiers' eyes and face by projectiles and fragments is well-documented (Madler et al., 1993). Even the most insignificant projectile that would cause little or no damage to the rest of the body can incapacitate a combatant for several hours if it comes in contact with the eye. The ballistic eyewear to be purchased by the Canadian Army should dramatically reduce this threat to the soldiers' eyes and in conjunction with a helmet visor, minimize this threat to the entire oculofacial region.

The HF evaluation of ballistic eyewear concepts followed a systematic approach. The investigation included:

- Literature Review
- User Needs Analysis
- Technical/ Optical Requirements Analysis
- Controlled HF Field Trial
- Eyewear Durability Trial

HF performance and technical requirements for CF ballistic protective eyewear were drafted from insights gathered during the review of the scientific literature, casualty databases, military studies, product literature, and the draft Statement of Operational Requirement. A range of representative COTS eyewear samples were then procured in small numbers to evaluate the

features and capabilities of current protective eyewear systems. A series of focus groups were then conducted with both prescription and non-prescription lens wearers from across the operational communities to determine which features would be essential and/or desirable in a combat capable spectacle system (Humansystems, 1997).

The information provided by the initial series of focus groups significantly reduced the number of options to be evaluated in the HF controlled field trial and in the laboratory technical and optical testing. The primary aim of the field trial was to develop HF performance specifications that could be incorporated into the requirements package. The secondary aim of the trial was to evaluate the suitability of various eyewear features incorporated into specific COTS eyewear designs. The aim of the technical testing was to develop definitive optical and materials specifications that could be combined with the performance specifications provided to industry (Hovis and Chou, 1998). A summary of the non-impact standards developed for ballistic protective eyewear is provided in Table 1 on pages 12 and 13.

A two-day field trial was undertaken at CFB Winnipeg, over the period 9-10 October 1997. Three COTS eyewear systems were evaluated by a total of 23 participants (15 non-prescription users and eight prescription users). For each group, a repeated measures comparison between eyewear conditions was possible (n=15 for non-prescription users and n=8 for prescription users). The order of wear was balanced amongst participants. Human factors tests included assessments of fit, and adjustability, performance of selected obstacle and battle tasks and clothing and equipment compatibility assessment. Data collection included questionnaires, focus groups, performance measures and human factors observer assessments. See figures 2 and 3.

The utility and acceptability of a shield or mono-lens system was rated significantly more favourably than either a sealed goggle design or common dual lens designs. Goggles were deemed unacceptable from a comfort standpoint due to the constant contact of the face seal and the increased fogging of eyepieces compared to spectacle systems. Goggle systems do provide better protection from dust then spectacle systems but unless the entire goggle frame is constructed of polycarbonate the ballistic coverage is inferior to shield type eyewear.

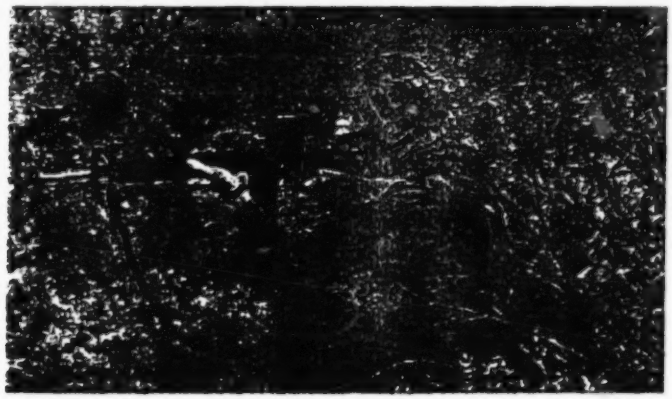

Figure 2. Field Manoeuvres

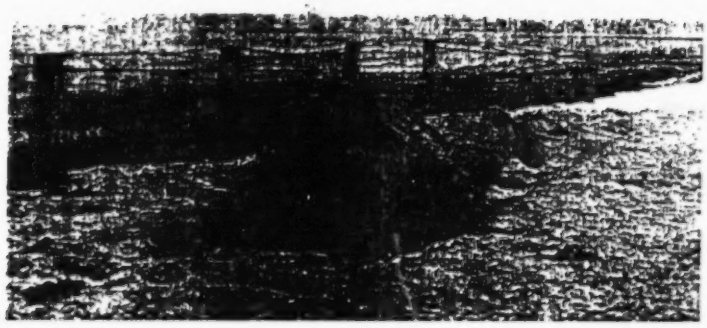

Figure 3. Obstacle Course

Users did not believe it feasible to provide the varied types of protection desired in a system that would require the changing of two separate lenses, as would be the case in traditional spectacle designs. Participants attributed the superior acceptability of the shield systems to aesthetics, comfort, stability, perceived compatibility, and optical performance. The interchangeable lenses required for solar and laser protection can be made more cheaply, and installed more quickly than dual lens systems. The prescription and non-prescription wearers also selected a number of features that would give them a stable, comfortable fit, for example adjustable temple arms, adjustable lens tilt, a non-slip nose bridge and interchangeable arms.

Overall, participants rated a number of criteria in the highest importance category for any future ballistic protective eyewear: weapon compatibility, fit, anti-fog protection, durability, corrective lens capability, anti-scratch, optical performance, stability, equipment compatibility, anti-glare, field of view, physical comfort, and task performance. Focus group discussions confirmed the importance of these criteria for the selection of ballistic eyewear.

Participants also rated several criteria as being in the moderate importance category: ballistic protection, UV protection, adjustability, laser protection, retention, balance, mission configurable, ease of replacement, thermal comfort, bulk, and lens coverage.

Participants then rated several criteria in the lowest importance category as well: side protection, stowage, clothing compatibility, camouflage, lens shape, and appearance. It is evident from this wide range of selection criteria that soldiers had definite ideas about what was important in combat capable eyewear.

Ballistic testing is currently underway at the CF's Defence Research Establishment Valcartier (DREV), to determine the ballistic protective standards that can be expected from COTS systems. The target for ocular protection in eyewear is 215 m/s for a 1.1g FSP (fragment simulated projectile), accomplished with a 3mm polycarbonate lens. A protection level in the 400 m/s range will be pursued for the visor with a combination of polycarbonate and other materials.

Incorporation of Corrective Vision

In view of the significant percentage (36%) of CF combat arms personnel that wear or require corrective lenses (Angel, 1996), a separate investigation was undertaken to determine the best approach for providing ballistic eye protection to prescription users. The various inservice and COTS protective eyewear systems were examined to determine the possible alternatives for providing ballistic protection to corrective lens wearers. This initial investigation revealed three possible approaches:

1. Incorporate correction into the ballistic layer itself. i.e. polycarbonate lens in existing or safety frames. – see figure 4.

2. Attach a corrective lens underneath the ballistic layer. i.e. a snap on insert – see figure 5.

3. Wear the protective layer over top of existing corrective eyewear. i.e. goggles, visor, over the glasses (OTG) sunglasses.

These alternatives were presented to participants of a series of focus groups in order to select the alternatives that would receive further testing. Alternatives 1 and 2 were rated as most acceptable so several COTS samples of each were procured.

Figure 4: Incorporation of corrective lenses into a dual lens safety spectacle

Prototype corrective ballistic protective eyewear systems representing the range of features and concepts were evaluated with 19 soldiers at CFB Petawawa during the period 9 to 12 June 1997 and with 10 soldiers at CFB Winnipeg during the period 9 to 10 October 1997. The utility and acceptability of a corrective lens that attaches to the nose piece under the protective one-piece shield (Fig. 5) was rated significantly more favourably than the other

approaches. Participants from both trials agreed that the superior acceptability of the insert systems was due to excellent aesthetics, comfort, stability, and perceived compatibility and optical performance. The insert system was seen to offer two main advantages; the interchangeable shield allows prescription wearers to have a tinted lens for sun or laser protection with only one set of corrective lenses, and having a shield in front of the insert will provide additional protection against scratches and abrasion from dust etc..

Figure 5: Insert system behind a Mono lens protective shield

The question then arose as to how to achieve compatibility of the ballistic protective eyewear system with the NBC respirator. For most soldiers doffing the eyewear before donning the respirator was not a problem but what of the corrective lens wearer?

NBC Spectacles

The CF currently use a general-purpose combat spectacle designed in the early seventies (Dean and Cressman, 1973) for corrective vision in the field (Fig. 6). This system has provided usable corrective vision primarily underneath the respirator for over twenty years. Evidence revealing that the current combat spectacle degrades the seal of the newer C4 respirator and the discomfort associated with this item (i.e. pressure points on nose and ears)(Donati et al,1991), lead to a search for a more viable option.

A replacement spectacle development project was initiated with the following objectives (Meunier, 1992):

- to be compatible with the C4 and AC4 (Aircrew) respirator
- to minimize faceseal leakage due to the spectacles
- to maximize comfort/wearability/stability/durability/usability
- to allow use of bifocals
- to minimize the cost and associated logistics of the end item
- to build in flexibility for other non-NBC uses

(Figure 6. In-service NBC respirator spectacles)

As for the ballistic eyewear project, a number of different alternatives were identified for incorporation of corrective vision with the C4 respirator. These approaches included:

1. a spectacle system;
2. an insert system inside the respirator; and
3. corrective vision incorporated in the C4 Respirator lens assembly.

The first approach was a traditional spectacle design, the second was an insert design to be attached inside the C4 respirator, while the third was grinding or bonding prescription lenses into the C4 respirator polycarbonate eye piece assemblies. An analysis of the cost and difficulties associated with built-in prescription lenses eliminated the third option of using specially manufactured C4 respirator lens systems. Using new materials and molding techniques, prototypes of each of the first two designs were produced and refined through a series of testing and evaluation. The resulting frames for each alternative were very similar in appearance and dimension except for their respective retention systems and concept of use.

The traditional spectacle option, (Fig. 7) features a nylon frame capable of retaining 3mm-polycarbonate lenses with a silicone nose bridge (not shown) and rubber retention strap.

(Figure 7. Traditional spectacle prototype)

The yoke and harness system allow the user to adjust the pantoscopic tilt of the frame by simply sliding the retention strap up or down on the yoke. An adjustable harness is envisioned for the production model to further improve the fit of this item, but was not pursued in the prototyping phase.

The insert system has the same frame design but instead of using a yoke system, attaches directly to the respirator nose cup (fig 8).

Figure 8. Insert attached to nosecup of C4 respirator

The attachment to the nosecup is achieved through a simple clip that can be removed easily for eyewear cleaning or mask decontamination. In this concept, soldiers requiring visual correction would wear a separate combat spectacle for general field use that would be removed as part of the mask donning process. The potential benefits to mask fit were considered significant enough to consider this option and the need for multiple corrective lenses.

Human*systems* Incorporated was tasked by the Defence and Civil Institute of Environmental Medicine (DCIEM) to undertake a human factors evaluation of the prototype plastic injection moulded NBC spectacles, and the prototype correction vision *Inserts* (Humansystems, 1998). The results of this evaluation were designed to provide direction to DND as to which concept is best to pursue from a HF perspective. The aim of these field trials was to evaluate HF compatibility of the prototype NBC spectacles (*Prototype*) and the corrective vision inserts (*Inserts*), with the C4 respirator and various items of clothing, equipment and weapons systems. The *Prototype* and *Inserts* were compared using the in-service combat spectacles (*In-service*) a baseline for comparison. The HF trials included a controlled army field trial and a navy user trial.

A three-day trial was undertaken at CFB Petawawa during the period 10 – 12 June 1997 with soldiers from 3 RCR, 2 RCHA, 2 CER and the RCD. Thirty-seven soldiers (Infantry-9, Artillery-11, Armour-7, and Engineers-10) undertook a battery of HF tests. Participants wore each of the three possible eyewear systems conditions in a repeated measures experimental design. The order of eyewear was balanced among participants. Human factors tests included assessments of fit, adjustability, stability, thermal and physical comfort; ease of use, battle tasks;

equipment, crew station, and clothing compatibility; durability. Data collection included questionnaires, focus groups, performance measures and HF observer assessments.

Additionally, 33 regular forces sailors were from CFB Halifax were selected for a user trial (November 1996 to March 1997). Each subject was issued the two concept corrective vision devices along with task diaries. Ten subjects returned Log booklets and participated in an exit focus group discussion.

Each combat spectacle concept had its pros and cons. Several manufacturing or design flaws were noted, but did not negatively affect the results of these trials. The subjects provided valuable feedback on the suitability of each concept as a NBC spectacle. When asked outright which concept they would select, 83.8% of Army subjects chose the *Prototype* over the *Insert*. The results of the Navy trial while not as statistically relevent tended to support the Army trial subjects' conclusions. Based on the results of the trial, no concept is ready for issue, however from the results, the *Prototype* represents a more viable concept. Based on the results of these HF trials, it was recommended that further development and testing of a *Prototype* design concept be pursued.

DISCUSSION

The requirements of these two projects, ballistic protective eyewear and respirator spectacles, if viewed in isolation would require that the soldier be issued at least three pairs of prescription lenses: one for in-garrison/off-duty use, one for general field use and one for use with the respirator. This potentially unwieldy and expensive approach can be avoided by the integration of the prescription lens requirements into a single system for field use.

The timelines and approaches differ significantly for these two separate eyewear projects; the C4 respirator corrective vision project is an in-house development recommended and initiated within the R&D branch, while the ballistic eyewear project is a new item being brought in to service to fill a recognized need. The intention for the NBC spectacle project is to have an improved product available to gradually replace the in-service item while, the intention for the ballistic eyewear project is to procure a large quantity of COTS or NDI eyewear that meets defined performance and technical specifications.

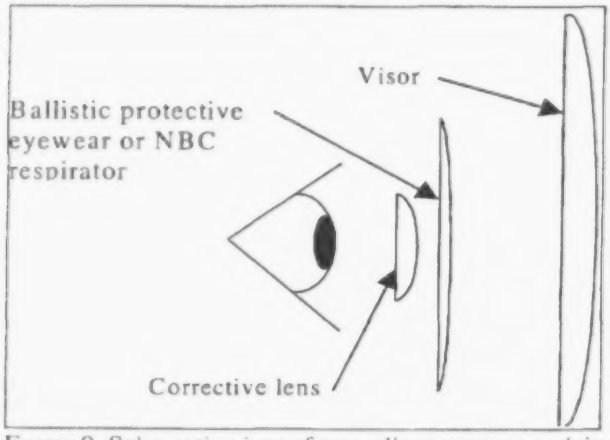

Figure 9. Schematic view of providing corrective vision and protection

The work done to date on these two projects suggests that an integrated approach to providing corrective lenses offer the best chance for success (Fig. 9). It is envisioned that the traditional spectacle concept for the respirator will be further refined to be compatible with the future ballistic eyewear and oculofacial protection systems, thus fulfilling the needs of both projects. In situations where there is deemed to be no NBC threat the corrective lenses will be snapped on to the nosepiece of the ballistic eyewear (similar to the insert system), with the yoke and head strap removed. If an NBC threat becomes likely, the yoke and strap are replaced and the clip retaining the corrective lens frame undone. In the event of an NBC attack the ballistic eyewear can be removed easily and the respirator donned rapidly while the corrective lenses remain in place strapped to the head. In this way corrective lens wearers do not sacrifice clear vision for protection at anytime. This will solve a longstanding dilemma faced by corrective lens wearers, lead to a significant increase in operational capability and result in a decrease in casualty rates due to eye injuries.

FUTURE WORK

There are several outstanding issues that will be addressed by further testing in the coming months for both the NBC spectacles and the ballistic protective eyewear before they can be integrated into a single system. A series of focus groups will be held with representative users of all three environments to validate that this integrated approach is acceptable to the end user and identify any unforeseen design problems. Recommendations from the Army and Navy trials on NBC spectacles will also be incorporated into design revisions of the spectacle system to make them more robust, and offer more sizing options.

Further technical testing remains to be done on the ballistic protective eyewear to ensure that the specifications developed are achievable by industry. Upon completion of the performance and technical specifications package, a contract will be let and a COTS/NDI system purchased. The winning bidder will have shown the ability to meet or exceed the specifications developed including the capability to provide a corrective lens retention system. Once the CF has received bids on the BEW, a further HF trial and technical testing will be conducted to evaluate compliance with all specifications. The ballistic protective eyewear purchased will then be used as a platform to complete the design of the integrated corrective lens system. A final HF trial to validate the design of the integrated corrective lens system will then be conducted before the item is manufactured for general issue.

CONCLUSION

Success in this project will finally fill a long-standing requirement to replace the in-service spectacles with ones that are operationally effective, comfortable, economical, and durable. This highly configurable, yet simple, design will take advantage of years of development work on the NBC spectacles and take advantage of the short timelines inherent in a COTS procurement project. This system will provide all Canadian soldiers the best laser, solar, ballistic and NBC protection currently available without compromising vision or comfort. The corrective lens wearer can now expect to maintain his operational effectiveness in all threat scenarios to the same levels as his fellow soldier. This project should also help to stem the tide of eye injuries on today's battlefield by providing a comfortable, usable solution for all soldiers.

Table 1. Summary of the Draft Non-Impact Standards for Ballistic Protective Eyewear.

Property	Standard	Reference
Optical Power	+0.06 to –0.125 Dioptre for plano lenses in any meridian	American National Standards Institute (ANSI) Z87.1-1989 See reference no. 10
Definition	0.79 cycles/mm using the 1951 USAF Test Pattern	ANSI Z87.1-1989
Prism	0.125 Prism Dioptre in any direction of any individual lens. 0.25 Prism Dioptre imbalance between lens pairs	ANSI Z87.1-1989
Distortion	No visible distortions of a grid when the eyewear is worn in the normal position	Draft standard See reference no. 5
Warpage	±0.50 D between the principal meridians	Canadian Standards Association (CSA) Z94.3-92 See reference no.13
Luminous Transmittance Clear	85% Photopic, Scotopic, and P43	Draft standard
Luminous Transmittance Sunglass	10% to 20% ±0.1 density units for uniformity within a lens and between lens pairs	Draft standard
Neutrality of tint Sunglass	Average deviation from D65 is no greater then ±15% measured in 2nm intervals. Red Light Visibility Factor should be between 0.9 and 1.1	Draft standard
Luminous Transmittance Laser Protective tint $\lambda_{1,2}$	40% for Scotopic, Photopic, and P43. 4.0 optical density (OD) at 694 nm & 1064 nm	Defence Personnel Support Center-DPSC-FQSe See reference no.14
Luminous Transmittance Laser Protective tint $\lambda_{2,3}$	40% for Scotopic, Photopic, and P43 4.0 OD at 532 nm 694 nm	DPSC-FQSe
Luminous Transmittance Laser Protective tint $\lambda_{1,2,3}$	9% Scotopic, Photopic and P43 4.0 OD at 532 nm, 694 nm, and 1064 nm.	DPSC-FQSe
Narrow Angle Scatter (i.e. Haze)	A luminance reduction factor no greater than 0.5 $\frac{cd}{m^2 lux}$	European Committee for Standardization Central Secretariat EN-167 See reference no.11
UV Protection	1% Maximum transmittance for UVB & UVA	CSA Z94.3-92
IR Protection	None required	None

Table 1. Continued

Property	Standard	Reference
Abrasion Resistance	A luminance reduction factor no greater than 5 $\frac{cd}{m^2 lux}$ after exposure to falling sand.	EN 168 See reference no.12
Field of View	Device does not restrict the field of view by more than 10° in any meridian. The normal field of view is defined with the headgear in place.	Draft standard
Resistance to Heat	No optical, structural or mechanical defects after heating 72 hours at 70°C	DPSC-FQSe
Resistance to Cold	No optical, structural or mechanical defects after cooling 72 hours at -50°C	DPSC-FQSe
Ignition/Flammability	Heated Rod Test No ignition or sustained glow	EN 168
Resistance to Humidity	No optical, structural or mechanical defects after exposure to 90% (±5%) humidity at 50° C for 24 hours	CSA Z94.3-92
Resistance to Solar Radiation	No optical, structural or mechanical defects after exposure to 1100 watts/m^2 radiation from an xenon light for 48 hours	CSA Z94.3-92
Resistance to Chemicals	No optical, structural or mechanical defects after exposure to various chemicals for 24 hours	DPSC-FQSe
Resistance to Fogging	None at this time	To be developed
Coverage	Probe test with headgear on headform. No contact with headform eye from the nasal and superior directions, at angles less than 60° from the inferior direction and 110° from the temporal direction.	Draft standard

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